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ScienceDirect
Procedia Engineering 150 (2016) 1297 – 1302
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2016

Moldboard Surface Universalization of the Ploughshare Operating Unit

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Abstract

This paper deals with a way of universalizing of ploughshare-moldboard surfaces (PMS) due to spatial rotation to work on different soil types and at various speeds. The paper presents a newly developed way to compare the topology of two ploughshare-moldboard surfaces (PMS) using the filter-function criterion and original methods to input data on the PMS topology and to approximate these data with polynomial dependencies for smoothing and providing the unimodality of the objective function of optimization when using the Hooke-Jeeves method. Thus, the optimal angles of rotation and movement to obtain the minimum deviation of the PMS for comparison and the basic one are found, with the practical results of using the method developed for PMS universalization being presented.

Peer-review under responsibility of the organizing committee of ICIE 2016

Keywords: PMS universalization; spatial rotation; topology; normal combining; agrotechnical requirements.

1. Introduction.

The tractor is well-known to perform its operations only as a part of a unit, with its technical performance being largely determined by the parameters of operating tools. Different soils because of their physical-mechanical structures and mouldboard ploughs moving at different speeds for efficient tillage are well-known to require working units with different parameters. Using of ploughs with PMS optimal parameters makes it possible to obtain minimum costs and maximum tillage quality. PMS optimal parameters are the following: the

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Peer-review under responsibility of the organizing committee of ICIE 2016
doi:10.1016/j.proeng.2016.07.297

ploughshare angle to the bottom and the furrow wall, the mouldboard bend characterized by the difference between the maximum and minimum angles of the direction the moving operating element, the upper and lower parts of the mouldboard, etc.

According the classical tillage approach the rectangular section of a soil layer is rotated alternately about its faces, with the operating tool moving forward. Therefore, the spatial trajectory of each point of the soil layer is a helical line with some lead. If the lead is the same for each point of the soil layer section, the rotational surface will be helical. If the lead changes, the surface will be semi-helical or cultural.

The lead (*S*) of helical lines and the laws of its changing are determined with the agronomic requirements to soil overturning (*b*) and the speed (V_0) of a moving plough [1, 2, 3, 4].

2. Relevance.

The optimum shape of a PMS depends on the speed (V_0) of its movement. For example, the PMS lead dependence (*S*) for the surface of the cultural type is:

$$S = S_0 + \frac{b}{tg\mu} \tag{1}$$

where V_0 is the operating speed of the forward plough movement;
b_0 is the operating width of the plough;
$g = 9{,}81$ m/sec^2 is the gravitational acceleration;
b is the radius of rotating soil layer;
μ is the inclination angle of the layer cross section along the moving case;
S_0 is the initial lead of the helical line;

$$S_0 = \frac{2}{3}\pi V_0 \sqrt{\frac{b_0}{g}}. \tag{2}$$

For PMSs of the semi-helical type the law of changing the lead is the following [5, 6]:

$$S = \frac{2\pi V_0}{\sqrt{zg}} b. \tag{3}$$

It is easy to notice that with the increased speed (V_0) causes the increase of the lead value (*S*), thus reducing the inclination angle of the horizontal parts to the furrow wall that affects the ploughing quality [1-3].

3. Problem statement.

Adjusting the operating unit of a plough makes it possible to get a PMS type as the most efficient one to provide the best tillage quality and to use the same operating unit for different types of soils and operating speeds. Therefore, the primary objective of the study is to develop a universal plough operating unit suitable for different speeds and soil types due to its spatial rotating and shifting.

4. Theoretical research.

To universalize the PMS plough is necessary to define movements necessary for the PMS designed for operating at the speed $_{V1}$ to make it maximum similar to the PMS designed to operate at the speed V_2. Thus, the following rotation algorithm is developed (Fig. 1):

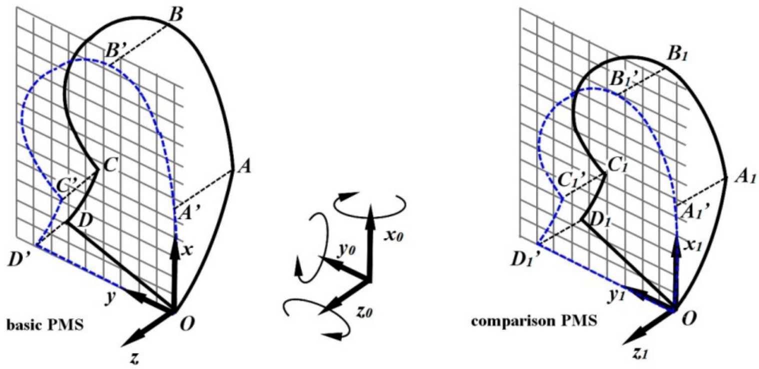

Fig. 1. The comparison PMS, its rotations and shifting's

1. both PMSs (the basic and the comparison ones) are approximated with the least-squares technique a set of planes;
2. the normal for these planes are defined:
3. the normal are combined by performing a series of consecutive turns of the basic surface:
   - the turn around the axis z at the angle ψ (the new coordinate system is x′y′z′) [7, 8],
   - the turn relative to the axis x' at the angle θ (the new coordinate system is x″y″z″),
   - the turn relative to the axis z″ at the angle φ.

The transformation matrix of coordinates is [3]:

$$M = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \tag{4}$$

where

$m_{11} = \cos\varphi \cdot \cos\psi - \sin\varphi \cdot \cos\theta \cdot \sin\psi;$

$m_{12} = \cos\varphi \cdot \sin\psi + \sin\varphi \cdot \cos\theta \cdot \cos\psi;$

$m_{13} = sin\varphi \cdot \sin\theta;$

$m_{21} = -sin\varphi \cdot \cos\psi - \cos\varphi \cdot \cos\theta \cdot \sin\psi;$

$m_{22} = -\sin\varphi \cdot \sin\psi + \cos\varphi \cdot \cos\theta \cdot \cos\psi;$

$m_{23} = \cos\varphi \cdot \sin\theta;$

$m_{31} = \sin\theta \cdot \sin\psi;$

$m_{32} = -\sin\theta \cdot \cos\psi;$

$m_{33} = \cos\theta.$

After the PMS final rotation the coordinates of the new surface are determined:

$$\begin{Bmatrix} x_1 \\ y_1 \\ z_1 \end{Bmatrix} = [M] \cdot \begin{Bmatrix} x \\ y \\ z \end{Bmatrix} \tag{5}$$

where x, y, z are the coordinates of the PMS basic points in the original coordinate system,
$x_{1,}, y_1, z_1$ are the coordinates of the comparison PMS points after a series of successive turns.

The resulting surface will be maximum similar to the required PMS to operate at the speed V_2.

To solve the problem of optimizing the comparison PMS position relative to the basis PMS the Hooke-Jeeves method of coordinate descent is chosen as it has a number of advantages:

- it is not necessary to calculate the gradient of the objective function;
- the function itself can be specified in any way;
- it is easy to implement on a computer [7, 9].

According to the chosen method some numerical calculations have been carried out to obtain the necessary rotation angles and shifting along three axes. Currently, for each PMS type there are found optimal angles between the furrow wall and the ploughshare of an operating unit:

- the angle for a high-speed PMS is 36°,
- the angle for a semi-helical PMS is 40° (it is a variety of a high-speed PMS)
- the angle for a cultural PMS is 44°,
- the angle for a cylindrical PMS is 48°.

Thus, to operate at different technological speeds plough units are to be rotated within the angle equal to 12°. The lateral shifting corresponding to this angle is a=70 mm. According to agro technical and technological requirements for ploughing widths, the first ploughing unit is fixed without any shifting, the second, the third and the fourth ones depending on their speeds are to have shifting's equivalent to a, 2a and 3a, respectively (Fig. 2). Changing the setting angle of the operating unit to the furrow wall makes it possible to get the most efficient type of PMSs.

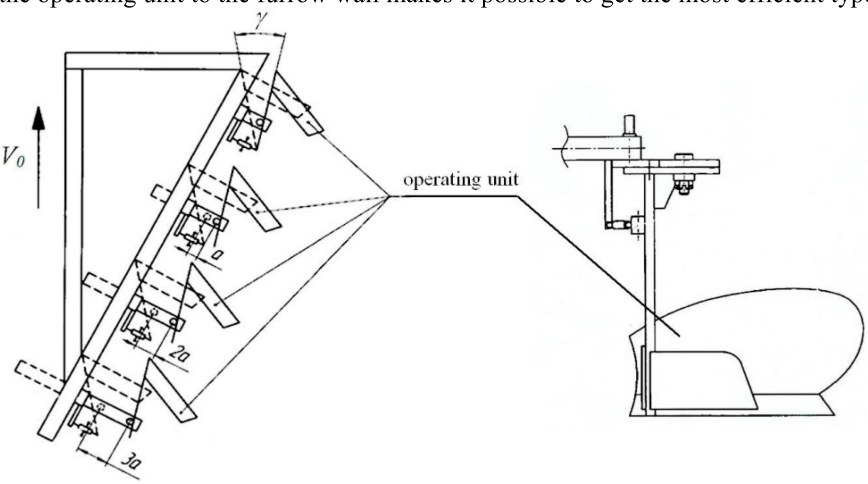

Fig. 2. The universal plough adjusting to operate at specified modes

5. Practical application.

To determine and adjust the parameters of PMS operating units to deal with different soil types at different speeds of a moving aggregate a number of technical solutions have been proposed, the main distinctive features being their PMS angles to be easily adjusted. The technical solutions have been also patented [10-14].

First, the angle of setting the share plough to the furrow wall and the value of its lateral shifting according to the speed of the moving machine is computed. Thus, the parameters of the basic PMS designed to operate at the first predetermined speed of the moving tractor unit, and the parameters of the PMS designed to operate at the second predetermined speed are loaded in the computer. Then both PMSs are graphed and approximated by their planes, with the normal to be found for the planes. Then, the obtained normal are combined and the numerical values of the angle of setting the share plough to the furrow wall and its lateral shifting necessary to rotate and shift the basic PMS according to the predetermined speed and the agro technical and technological requirements for ploughing widths of operating units. The parameters are obtained by adjusting the basic PMS of the plough operating parts by its successive rotations and shifting's.

The regulation of the universal plough angle of setting of the operating unit to the furrow wall is realized with a controlling system consisting of a hydraulic cylinder and a telescopic arm to connect the operating unit and the support bar (Fig. 3). The telescopic arm is a square tube with a 1-2 mm gap between the tubes. One end of the arm is rigidly fixed on the plough top platform, with the other one moving freely with the following fixing. The number of fixing holes in the telescopic square tubes of the upper and lower platforms corresponds to four corners standard for setting the operating unit to the furrow wall for the four PMS types that exist: cylindrical, cultural, semi-helical and helical.

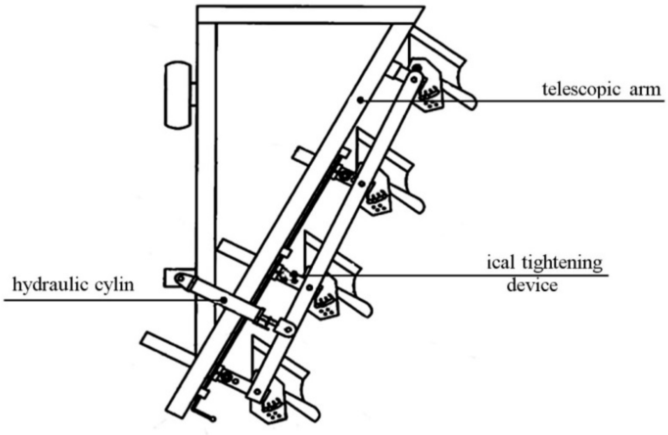

Fig. 3. The plough with a mechanism for PMS adjusting

The operating unit is rotated by using a helical tightening device connected with joints to the operating unit post. All the plough operating elements are interconnected by a lever mounted on the axles of the telescopic arms with gaps to be rotated relatively to the axle of the first operating element fixed to avoid any lateral movements.

A moldboard plough with variable PMS parameters is adjusted according to soil and climatic working conditions which may widely vary during relatively short time periods. The regulation of PMS parameters includes the adjusting of necessary angles of setting the operating unit to the furrow wall.

According to the developed drawings PMS samples were manufactured at the plant "Stankomash". They have passed field tests at the instructional farm of Chelyabinsk Institute of Mechanization and Electrification, the test results proving the proposed method to be viable for PMS special moving [15].

6. Conclusions

The proposed method of PMS universalization due to its spatial rotation to operate on different soil types and at aggregate various speeds is as follows:

a) the available basic surface designed to operate at the speed V_1 is approximated with some planes and the normal for the planes defined;

b) the surface for operating at a different speed V_2, higher or lower, can be experimentally specified or calculated. This surface can also be approximated by some planes, with the normal being defined;

c) then the normal obtained are combined due to successive rotations of the basic surface normal around the axes (z) and (x) and the angles needed to rotate the basic PMS, its special parameters being maximum similar to the desired surface, are found;

d) the quality concerning the coincidence of both surfaces is controlled by comparing the coordinates of both surfaces;

d) the obtained parameters of spatial rotating and shifting of the existing PMS are applied to a real plough with appropriate mechanisms.

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